Development of Concept Inventories for Statistical Physics and Quantum Mechanics to Enhance Learning of Solid State Physics: A PER Study

A Synopsis of Ph.D Thesis
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1. INTRODUCTION

In recent years subject based education research has gained lot of prominence in effective delivery of subject learning. This is because of a general experience that subject experts are better equipped to draw strategies for effective learning of a subject with well defined subject based learning outcomes [1]. Physics Education Research (PER) [2] has led the way, which is bringing fresh ideas and approaches in the teaching and learning of the subject. This field of research is still young but has created a self–effacing research foundation that is bringing numerous reforms in physics education and has also inspired similar research in other disciplines [3-4]. The major factors which have made physics education researchers to think about this are:

(a) decline in the number of students in science in general and physics in particular.
(b) enhanced results of physics education research in improved learning by students.
(c) advantages of the introduction of latest technologies as teaching and learning tools.

The decline in the number of students opting for science stream is a global concern now days [5]. Educators are trying to find out the causes and are seeking remedies for such situations. They are trying to change both content and traditional teaching-learning techniques [6]. Traditional teaching is based on content laden-lecture based format (where teacher assumes that students are lacking information and he/she has to supply information in an effective way), outdated instruments and algorithmic exam. Furthermore, in a class where students of diverse learning styles are sitting, only traditional teaching methods become insufficient and introduction of new techniques become essential. The researchers have found that many students taught in traditional format lack a solid conceptual understanding of concepts, find trouble in quantitative problem solving and other skills [7]. In the words of Carl Wiemann (Noble Prize winner in physics in 2001 and a practitioner of Physics Education Research), *The purpose of science education is no longer simply to train that tiny fraction of population who will become next generation of scientists. We need to make science education effective and relevant for a large and necessarily more diverse fraction of the population* [8].

1.1 What is Physics Education Research (PER)

Physics Education Research (PER) is a recently emerged sub field of research in physics departments and physicists have begun to treat the teaching and learning of physics as a research problem similar to any applied science. It is based on the learning theory with the aim of introducing well defined learning outcomes/objectives for improving the methodology of teaching and learning assessment.
It involves

- Systematic observation made of student's thinking and interpretation of concepts and then data collection.
- In-depth probing and analysis of students' thinking by theories or models constructed to interpret the observations.
- Based upon theses theories and models, instructional strategies are developed, implemented and finally assessed.

At present physics education research (PER) is the most advanced science related education research focusing on the knowledge of student learning which has been used to develop innovative teaching methods, informative assessment techniques and intentionally designed curricula to improve student's learning. The results of PER have also helped the curriculum developers and textbook writers to redesign and develop curriculum and instructional methods that can change student's preconceptions more effectively. The main focus of physics education research (PER) is to find the gap between what is taught and what is learnt and looking for research based strategies to bridge that gap [9]. In other words physics education research is trying to identify student's misperception of core concepts of physics, both before and after the completion of a traditional course of physics. There are number of studies focusing on the preconception of students in physics [10-13]. Physicists have found in their research that students even after completing their physics course were unsuccessful at answering questions on mechanics (a most elementary sub field of physics) known as Force Concept Inventory FCI [14]. It is also widely recognized by Physics Education Researchers that students entering the classroom are not like a *blank slate* but they bring their own mental model about a concept [15] with them in the class. Most often their concepts are not matched with what is taught in the class and the learners show a resistance to change and to get new knowledge. As a result of which they do not develop functional understanding of concepts of physics. Therefore, at this point the role of a teacher becomes very important as he/she has to identify the preconception of the students and try to provide activities that can induce students to develop a good functional understanding of a basic concept. However, the developed strategies of PER are not used much at undergraduate level, to teach physics courses, in India, which is urgently warranted.

1.2 Research Trends in Physics Education Research (PER)

The repeated pattern of responses of students at different times and places lead to generate theories and is called *basic PER*. The results from basic PER are used by researchers to modify instruction, examine the educational efficacy of new approach and use these results to further improve instruction. This is called *applied branch of PER.*
There are many areas under physics education research. Some of these are:

- *(i)* Conceptual Understanding and Problem solving
- *(ii)* Epistemological beliefs and Attitudes
- *(iii)* Technology
- *(iv)* Evaluation of Specific Instructional Interventions and Instructional Materials

1.2.1 Conceptual Understanding and Problem Solving

A good understanding of concepts seems to be a prerequisite for expert problem solving. This field focuses on conceptual gap between what instructors have presented and what students have learnt. There is development of reliable instruments/tools called concept inventories to assess students' understanding of some of the basic concepts of physics. Experts develop very clever questions and tasks for students that elicit difficulties in specific area. The tool can be used on a large scale and statistically valid inferences can be drawn from the quantitative data. The *Force Concept Inventory* (FCI) which is a multiple-choice test and probes students' ideas about the notion of force in Newtonian mechanics developed by Hestenes *et.* al. [14] is a well-known

example. The test items require the student to choose between the (standard) Newtonian concept and the prevalent common-sense alternatives. FCI has also called score of 60% on concept inventory as conceptual threshold and it has been concluded that below this threshold a student's grasp on concepts is insufficient for problem solving. A number of different concept inventories are now available e.g. quantum mechanics concept inventory, concept inventory on wave motion, statistics, chemistry and material science etc. The outcomes of these tests administered on a large number of students at different places have enhanced awareness among physics teachers that students can solve problems in physics without an understanding of the concepts that are involved. Consequently, an important outcome of these inventories has been the growth of PER based instructional materials. A pioneer in PER, the group at the University of Washington has focused on students' conceptual ideas in areas like mechanics, thermodynamics, optics, electricity and relativity. After doing considerable pedagogic research this group has produced books titled *Physics by Enquiry* [16] and *Tutorials in Introductory Physics* [17].

1.2.2 Epistemological beliefs and Attitudes

This field focuses on studies of epistemological beliefs and assumptions and how they affect learning. In this field the link between the learning behaviour of students and the ontological presuppositions and epistemological beliefs which they bring to the classroom is explored. As stated earlier researchers have found that students come to class not as a blank slate but with pre-conceptions in their minds. They hold many firm contradictory ideas, one they "believe" and another for the tests about the physical world that often conflict strongly with physicists' views. This growing trend in PER is to look at these factors that influence the learner's conceptual understanding of the domain. Cognitive researchers believe that our cognition, whether of things or ideas around us or of a formal discipline like physics, is controlled by another level of cognition sometimes called the 'executive function'. The executive level controls and affects our primary content specific cognition. One important kind of control is what Redish calls 'expectations'. This term includes students' ideas of what constitutes learning say physics as well as their ideas about their own role in the learning process i.e. what is expected from them. This field focuses on the attitudes, beliefs and expectations of students with which they come to class. University of Maryland group is working on this field. *The Physics Suite* by Edward Redish [18] is a book for physics teachers to improve their instruction by developing an overall understanding of students' beliefs and alternative conceptions.

1.2.3 Technology

This field focuses on PER based technological innovations to bring changes in physics instruction. In the last decade the use of educational technologies has increased tremendously and has created an impact on all areas of physics instruction, from course administration to problem-solving and to data collection in the laboratory. Some of these are

- Microcomputer-based labs (MBL) by Thornton and Priscilla Law [19-20]
- Video based labs developed by Beichner [21]
- Physlets Physics developed by Wolfgang Christian and Mario Belloni at Davidson College, and allow students to visualize and interact with highly complex and abstract physical concepts [22-24]
- Student Response Systems (Clickers)

- Web based assessment system [25]

1.2.4 Specific Instructional Interventions and their Evaluation

A common thread that underlies the various pedagogies is their emphasis on active (and often collaborative) learning made possible by the new technology. This field focuses on introduction of specific pedagogy in class room and its evaluation. Numerous studies have reported the impact of different pedagogies in classroom. Some of the PER developed pedagogical innovative strategies/techniques used world wide are:

(a) context-rich problems
(b) concept tests /peer instruction
(c) just in time teaching (JITT)
(d) interactive lecture démonstrations (ILDs)

(a) Context – Rich problems:
In this technique knowledge is transferred to new context and questions based on that context are designed. Researches of university of Minnesota in United State have designed this model for teaching introductory physics. At University of Minnesota, department of physics a group of students sit together and solve challenging problems which can not be solved by a single student. These problems are based upon fundamental concepts and principles different from traditional text book problems. This model tries to link the problems of physics with student's previous experiences and focuses students attention on the fundamental concepts required to solve the problems. It discourages the rote memory of formulae and helps students to understand physics concepts in the context of real world so that they can solve problems in a logical way instead of just using plug and chug strategy [26-27].

(b)Peer Instruction:
In conventional teaching, material is presented as a monologue in front of passive students sitting in a class and hardly any opportunity is given to students to think critically. Peer instruction model involves student in their own learning during lecture and focuses their attention on the concept. In this model lectures are blended with conceptual questions called Concept Test [28]. Peer instruction model was developed by Harvard physicist Eric Mazur [29]. In this model traditional lecture is stopped after five to seven minutes and then a multiple choice question is posed to students. Students are supposed to think and give their answers in one to two minutes. After this they then spend two to three minutes discussing their answers in groups of three to four, attempting to reach consensus on the correct answer. Students are polled for their final choices using flash cards or radio frequency "clicker system." This method helps to understand common difficulties in understanding the material and force students to think through arguments.

(c)Just in Time Teaching (JiTT):
JiTT is a teaching-learning strategy blending an interaction between web based study assignment and active learner in a classroom. JiTT strategy was developed in USA by Novak and is a student led approach [30]. In this model students are supposed to come to class prepared in understanding the concept of a particular topic prior to class. Between classes, students are required to complete brief, carefully constructed exercises called "Warm-Ups", and

submit them electronically. After that instructors review student's JiTT responses and re organize the upcoming classroom session incorporating the needs of students. This exercise not only helps the student to prepare for the class and develop meta cognitive approach but the instructors also gets an idea of thinking process and preconceptions of the student. The success of JiTT depends upon good questions which probe conceptual understanding in pre-class Warm-Ups. JiTT encourages contact between students and faculty, active learning as well as give quick feedback. JiTT is a powerful pedagogical strategy that uses technology to enhance students learning and increase retention in the class.

(d) Interactive Lecture Démonstrations (ILDs) :
Interactive lecture demonstrations is a student centered teaching method which helps students to develop functional understanding of physics. In this method teacher describes the demonstration. These demonstrations are designed to contradict students known misconception and try to bring a conceptual change. In this way students are encouraged to observe the physical phenomenon through experimental observations. This discovery based model was developed by Sokoloff and Thornton and extended by Redish and his physics education colleagues at the University of Maryland [31].

2. SIGNIFICANCE OF THE STUDY

The present research study has a lot of significance in science education in general and physics education in particular.

- Hypothetically, we believe that teaching physics in traditional way is neither yielding significant result nor attracting talented students.
- Introduction of research based teaching strategies in physics has the *measurable* learning outcome which can go a long way to improve the quality of teaching and can offer students a significant advantage in cognitive learning.
- Focusing on a particular subject (Solid State Physics) in the teaching of undergraduate physics to which Physics Education Research Strategies has been applied is likely to pave way for developing research based resource material for teaching this subject and also to provide a clear perspective in adopting this methodology to teach other subjects in undergraduate physics courses.

3. OBJECTIVES OF THE STUDY

Present study belongs to the emerging new field of physics called Physics Education Research [32]. The study will make use of primary data using questionnaires/surveys and concept inventories. The whole study will be divided into two parts. In the first part the learning styles prevalent among undergraduate students their epistemological beliefs, attitudes regarding physics will be studied using standardised surveys and then PER based technological innovations and specific instructional interventions to bring changes in physics instruction in the classroom using clickers(students response system) will be employed.
In the second part of the work learning objectives of solid state physics will be defined, followed by design and administration of conceptual surveys on statistical physics and quantum mechanics.
The main objectives of the study will be:

- To study the PER strategies which are in vogue at international level and to see what are the lessons to be learnt from such case studies of different countries.
- To identify learning styles, attitudes, epistemological beliefs and assumptions or in other words expectations of students studying physics.
- To empirically verify the learning styles, attitudes and beliefs of students.
- To identify the loopholes of the existing style of teaching/learning of solid state physics course.
- To define the learning objectives of the solid state physics course.
- To design the concept maps for identified topics of solid state physics course and to identify the role teachers can play in assisting students in the process of creating a mental map of the subject.
- To increase students engagement with the material of solid state physics to enhance their learning and consequently examination performance.
- To assess the impact of use of research based instructional strategies in teaching solid state physics at undergraduate level on overall learning behavior of students.
- To develop appropriate diagnostic and assessment tools based on the result of implemented strategy.
- To see weather it requires any reengineering of solid state physics syllabus.
- To find out the expected problems in the introduction and implementation of such strategies.
- To make out how can the present study contribute towards the development of multimedia aids of identified topics of Statistical Physics and Quantum Mechanics which are useful for the understanding of Solid State Physics course?

4. PROPOSED PLAN AND METHODOLOGY OF THE STUDY

This part of the synopsis provides a general overview of the models and the details of the specific research methods which shall be used in the research study.

4.1 Study of Learning Styles

Researchers in science and engineering education have found that conceptual learning of students is influenced by their learning styles. There are number of ways in which learning process can take place - by hearing and seeing; reflecting and acting; thinking logically and intuitively and memorizing and visualizing. It is expected by teachers that students should learn properly and enjoy the learning process. But sometimes a lack of motivation is found in students. This could be due to inability of students to gather and grasp information because of their different learning styles. Felder Richard has mentioned that some learners favour a particular learning style and if teaching style does not match with their learning styles then they encounter difficulties in learning [33]. Studies have also shown that students studying online course matching with their learning style (either sequential or global) showed better learning outcomes result than those who's learning style were not matching with the course delivered [34]. One of the tools to identify the learning styles of a learner is Index of Learning Styles (ILS) [35]. The result of ILS gives detailed information of relation between learners' characteristics and their performance. In this study:

- The ILS questionnaire will be administered to students of undergraduate classes studying physics at four different colleges of Shimla city, affiliated to Himachal Pradesh University Shimla.
- The responses obtained will be statistically analyzed to explore which learning style is significant in students of undergraduate classes studying physics.
- Further it will be investigated if there is a mismatch between learning styles of these students and traditional teaching styles in physics education and which type of PER strategies can bring significant improvement in removing this mismatch.

4.1.1 Research Questions

In this study following research questions will be posed.

1. Which type of learning styles is significant in students learning physics at undergraduate level?
2. Do the learning styles of male learners differ from female learners?
3. Does our methodology of teaching match with the learning style of students studying the course?
4. What should be done if learning style of student is not matched with standard method of teaching physics, to effect change in their learning style, so as to achieve better conceptual understanding?

4.2 Study of Attitudes Beliefs and Expectations of Students

It has been scientifically established by Physics Education Researchers that there is indeed a correlation between the learners' behaviour, their epistemological beliefs with which they come to the classrooms and their success in a course [36-42]. There are number of validated and reliable survey instruments which can be used to study the difference in the beliefs of a novice and an expert. This study will be made to explore Indian students' expectations and beliefs in learning physics at secondary and tertiary levels.

- For this Maryland Physics Expectation (MPEX) survey consisting of 34-items, based upon the statements about physics and the learning of physics will be used. This survey has been tested both for its validity and reliability and in this students are asked to respond to the statements using a Likert scale (agree-disagree).
- To carry out the study the items of Maryland Physics Expectations (MPEX) survey will be translated into Hindi language and administered in a bilingual format (both in English and Hindi) to facilitate easy comprehension by the students. Structure of the survey will be kept the same and the translated portion will be vetted by teachers teaching physics at undergraduate level to ensure that the meaning of the translated items does not get altered.
- The survey will be administered to Class 12, Undergraduate (B.Sc.) and postgraduate (M. Sc.) physics students, at the beginning and at the end of instruction.
- The survey will also administered, once to a group of college and university teachers to have an expert view.
- A comparative analysis of the students' expectations and their responses obtained from this micro level study with that of experts and similar studies conducted in other

countries will be made to see the gap between the responses of experts and students of India and other countries.

- For statistical analysis of the data and to see the correlation within the groups and across the groups for our sample the statistical package for social sciences (SPSS) will be used.

4.2.1 Research Questions:

The following research questions will be posed in this study:

1. Is there a difference in the attitudes and expectations of class12, undergraduate and post graduate level students?
2. How do these expectations change as students go from class12 level to post graduate level?
3. Is there a difference in the expectations of the students of these different classes before (pre) and after (post) the instructions given?
4. Is there a difference in the expectations of male and female students?
5. Is there a difference in the expectations of physics students studying in India and other countries?

4.3 Defining of Learning Objectives of Solid State Physics Course:

In the prevailing traditional courses of study for B.Sc. (Bachelor of Science), it is observed that if an exercise on identifying, clarity and specificity of a syllabus is conducted, it rates poorly on providing guidance to the teachers, students and the examiners regarding [43]:

(i) What should the teacher teach with regard to subject matter, activity, linkages with other subjects and topics and depth of treatment?
(ii) Why should the teacher teach with regard to the application of the topic to real life, student's skill development, student's knowledge development and student's presentation skill?
(iii) How should the teacher teach with regard to method of teaching, teaching learning aids, time allocation, class room organization, lesson plans and method of evaluation?
(iv) How does the teacher know what he has taught with regard to types of tests and frequency of tests?

So the first step to remedy the situation is writing of the learning/ instructional objectives. A good teacher always has these objectives as some kind of hidden curricula at the back of his mind, which is rarely articulated clearly in front of either the students or their peers especially at the undergraduate level. Learning/ instructional objective is a statement of what a learner will be able to do i.e. his/her performance capability, when the instructor has finished an instruction.

- In this part of the study, the Instructional/Learning objectives for undergraduate Solid State Physics course as prescribed in B. Sc. Physics (Honours and General) of Himachal Pradesh University, Shimla will be defined.
- The instructional objectives/learning objectives will be written by using Mager's approach [44] and will be classified using Bloom's taxonomy [45].

- An effort will also be made to make it ready for adoption in the class room to assist the instructor /examiner to write assessment tools (tests) to make an unbiased assessment of learner's performance.

The instructional objectives based syllabi can prove to be of immense value in uncovering the syllabus for the learner, its updating and evaluation. In an affiliated system of evaluation at least it can ensure that every teacher knows the scope of the content and the parameters on which performance of the learner is to be evaluated. It can also open doors to innovative ways of teaching the subject and help in identifying the learning gaps of learners and evolve physics education based strategies to bridge the gap. It indeed can prove to be bedrock of research based physics teaching. This study will not only be the first step to enhance learning but to make teaching research based as well, as has been practiced in US and West as a foundation of Physics Education Research

4.4 Development of Concept Inventories

Physics education researchers have developed and designed assessment tools, namely concept inventories/surveys to systematically assess and measure the pre and post knowledge of the learners, pertaining to basic concept domains particularly for introductory physics such as Force Concept Inventory (FCI).There are number of conceptual surveys/inventories designed and developed by researchers covering different physics domains [46-54]. These surveys have acted as a valuable tool for the teachers to find the misconceptions/alternative conceptions held by their students about that particular topic(s) and to develop new strategies to help them change towards expert view. When administered at the start of the new course, these surveys provide the picture of starting knowledge of the students and when administered at the end of a course, it gives feedback on those concepts that may need more attention or reveal the alternative conception held by the learners. By studying the wrong answers chosen by students for various questions, one can find out common misconceptions that persist even after instruction.

Solid state physics is the largest branch of condensed matter physics which deals with the study of the structure properties of solids and the relationship between the phenomenon of solids and physical principles behind them. Quantum mechanics is the key to understand the fundamental properties of matter, which is a collection of large number of microscopic particles (10^{23}), their spectra and chemical behavior. It fundamentally describes the behavior of particles at the atomic level and states that matter and energy have the properties of both particles and waves. Application of basic concepts of Statistical Physics provides foundation and scaffolding for understanding the physical phenomena in many body physics from microscopic point of view. At undergraduate level learners encounter the first applications of these concepts in the study of many (N) body systems (N of the order of Avogadro's number) such as gases, liquids and solid state physics which require an in depth appreciation of physical behaviour of such a large collection of particles. It is, therefore, expected that learners must have a good grasp of the basic concepts involved in quantum mechanics and statistical physics before they go ahead with the learning of a solid state physics course.

- An assessment tool, the conceptual survey to gauge the student's prior knowledge and depth of understanding of these two fields (Statistical Physics and Quantum Mechanics)

which is a prerequisite for understanding the course on Solid State Physics at undergraduate level i.e. Bachelor of Science (B.Sc.) three years course will be developed [55-58].

- Both these concept inventories will be administered to students before the starting of session and at the end of the session. The data will be collected from selected colleges of the Shimla city affiliated to Himachal Pradesh University Shimla. In these colleges solid state physics course is taught in undergraduate level according to the syllabus of Himachal Pradesh University.
- Surveys will also be administered to a group of teachers to get an expert view.
- For establishing the validity and reliability of the instrument the *Classical Test Theory*, which involves item analysis and test analysis, will be applied [59-62].
- An effort will also be made to identify epistemological beliefs/ misconceptions and strategies offered to remove learning gaps/misconceptions which are stumble blocks for the learners. This exploration and research of epistemological beliefs can also help teachers to know how learners perceive particular knowledge and justify their inferences.
- Spreadsheets will be developed to appreciate the finer nuances while visualizing the behaviour of the system.

4.4.1 Research Questions

The following research questions will be posed in this study:

1. Do UG students possess sufficient conceptual knowledge of statistical physics and quantum mechanics when they begin their solid state physics course?
2. Do students have misconceptions/alternative conceptions regarding a particular concept?
3. Do these misconceptions remain common or change as students go from UG level to PG level?
4. Do the instructions given in the class increase or decrease the misconceptions held by students?
5. Do epistemological beliefs play any role in students learning?

4.5 Turning a classroom into a classroom with Students Response System (Clickers)

One of the main focus of PER is to have a curricula which encourages active learning and peer cooperation. The traditional teaching method is passive or one way. Researchers have found that interactive or active teaching is more beneficial for both students and teachers. There are many tools and technologies available to make teaching more interactive and engage students using three H's: Head**,** Heart & Hands**.** One of such tools is Students Response System or Clickers. Clickers are hand held electronic devices which students in a classroom can use to answer their multiple choice questions projected through an LCD on a large screen placed in front of them [63-64]. Research has shown that this method offers students a significant advantage on learning the concepts of the topic being taught. The idea behind clickers is not new. Teachers have used interactive instructive questions to teach students at least from the time of Socrates to encourage students to construct their own knowledge structures. Clickers/ Audience response system or student response system is a wireless response system that allows instructors to ask questions

and gather instantaneous student responses during a class. Its technology consists of three components

- Transmitters also called Clickers
- Receiver
- Software

Each clicker has a unique number and it is possible to identify a students ID number with a particular clicker device. The teacher asks a Multiple Choice Question. The question is usually projected on a large screen in class. Students click their answers. The classroom computer registers all student responses in real-time. The teacher can instantly display a graph that shows how the class responded and discuss responses.

- To maintain student's attention in the class and also to check the understanding of the students' concept formation, Student's Response System (clicker technique) will be used.
- The class of B.Sc. third year students will be converted into clicker class room. Where Hyper-Interactive Teaching Technology (H-ITT) Students Response System software will be installed.
- Clicker questions on statistical physics, quantum mechanics and solid state physics courses will be designed.
- Use of blend of peer instruction and just in time teaching strategies of PER in classroom will be made.

4.5.1 Research Questions

The following research questions will be posed in this study:

- Does use of clickers improve the understanding of the subject?
- Does use of clickers increase participation and interaction in the class?
- Does use of clickers improve grades of the students?

5. WORK DONE SO FAR

This section highlights the work done so far according to our proposed plan as discussed in Section 4.

Study of Learning Styles

In order to study the learning styles of students of undergraduate classes studying physics in a three years degree course of Bachelor of Science (B.Sc.) of Himachal Pradesh University at four different colleges of the city [65]:

- The Index of Learning Styles ILS questionnaire, which classifies learners into four types of learning styles, active, sensing, visual, and sequential was administered to 424 students of undergraduate classes studying physics at four different colleges of Shimla city, affiliated to Himachal Pradesh University Shimla.
- The preference of the learning styles of these students for the four dimensions was observed by analyzing data.
- The analysis of this data revealed that there is a mismatch between learning styles of most of undergraduate students and traditional teaching styles in physics education. We found that majority of these students have *active, sensing, visual, and sequential* types learning styles. But in our traditional lecture based classes, active learners never get to do anything and reflective learner is never given time to reflect.
- The teaching styles of teachers in the colleges is in-compatible in many dimensions. The requirements of four (intuitive, verbal, reflective and sequential) learning styles, out of eight categories are met more or less by traditional lecture based teaching method but for other four dimensions some additional teaching methods especially multi - media techniques are required.

Thus ILS survey is a useful tool to find out the mode in which students learn. To have a success in work and life students must function well in each category. The primary goal of teacher is to help students to develop the characteristics of each category. For this he/she can tailor his/her lecture using some of the extra techniques to fulfill the needs of most of the students, to enhance retention rate and their performance. This way quality of physics education can be enhanced. In a class where students of diverse learning styles are sitting, teacher does not have to find out the learning style of each student. But efforts can be made to take care of at least each side of all learning styles dimension by using small number of additional innovative teaching aids.

5.2 Introducing Clickers in the Classroom

The result of previous study of learning styles of UG students indicates that they are **active**, **sensing, visual and sequential** type learners. To bring changes in physics instruction in the classroom, PER based technological innovation and specific instructional intervention called Classroom Response System or Clickers blended with peer instruction strategy was used. Students were asked specially designed, Multiple Choice conceptual questions on various topics of Solid State Physics course. Questions were having scientifically accurate concepts and prevalent student misconceptions. Such questions helped us to:

- explore pre-existing knowledge of students
- activate learning
- engage all students in classroom
- increase student involvement and attention

- get instant feedback
- assess student's understanding
- know whether the lesson is sinking in

We observed that students eagerly discussed the choices they have made. Use of clickers stimulated the interest and concentration of the students. Students were willing to ask questions and learning went on in the class.

5.3 Defining of Learning Objectives

The foundation and the first step to enhance learning and to make teaching research based as well learner centered, is to define the instructional/learning objectives. Also we observed that there are limitations in physics teaching and individual topics are taught without linking them with other topics. Physics Education Research emphasizes on the need to comprehend not only individual topics but inter-linkages amongst various topics. In this context some studies have highlighted the importance of cognitive coherence as an effective strategy for physics learning and to have hold over the subject. Bringing coherence should lead to the removing of contradictory ideas from the minds of students. A map is the best cognitive resource both for instructor as well as the learner to create a mental image or relational map of field of physics. In this part of the study:

- The Instructional/Learning objectives for undergraduate Solid State Physics course as prescribed in B. Sc. Physics (Honours and General) of Himachal Pradesh University, Shimla were defined using Mager's approach and classified using Bloom's taxonomy [66].
- To give an architectural view and also to provide a visual survey of conceptually connected material, we developed a map of Solid State Physics course. It was presented both in a pictorial and tabular format with recognition of sections of the syllabus as districts and sub districts. Further in each district and sub district, key concepts as land marks, variables involved as nodes, key physical equations as paths and limits on variables as edges or boundaries were identified [67].

These two exercises have helped us to reveal the hidden curricula in the circulated content of the subject of Solid State Physics to be learnt by the learners, to be taught by the teacher and to be tested by the examiner along with mental mapping of the subject. The idea of both Lynch and A.Tabor.et.al [68-69] is being extended in the study to bring forth cognitive coherence of the subject in a global manner, so that it can act as a bridge between the students journey through the subject and a pictorial reminder to them that the subject is not a mere collection of isolated facts, equations or derivations, but has a well knit hierarchical structure.

5.4 Identification of Epistemological Beliefs

Students' epistemological beliefs (i.e. beliefs about how knowledge is built) and attitudes have great impact on their approaches of learning and time spent on organizing their knowledge structure. Research has shown that students' expectations in physics, which emanates from attitudes, beliefs and assumptions about physics and its consequent learning,

play a very important role in the conceptual understanding of physics. Sometimes these prior beliefs can lead to different understandings of the same situations. It has been indeed established by the researchers that students' responses actually depend upon their expectations, and their expectations affect their understanding of the subject. Thus the awareness of pre knowledge or learners perception plays a very important role for the instructor to plan his/her teaching activities to make students link new material to what they already know. There are surveys which have been developed mainly by physics education researchers to measure the influence of epistemological beliefs and expectations on physics learning. These surveys known as attitude surveys or affective surveys probe learner's thinking about the process and the character of learning physics. They provide useful information on student perceptions of their classroom experience. They are different from the so called content surveys which aim to identify learning gaps or misconceptions in the subject, and reveal their perceptions on the content of a course, the effects of course innovations, etc.

- In this work use of Maryland Physics Expectations (MPEX) Survey has been made to probe students' understanding of the process of learning physics. The MPEX survey is very well tested both for reliability and validity. The purpose of the survey is to explore student beliefs in six main clusters: independence, coherence, concepts, reality link, math link and effort link.
- The survey was administered to 228 students. The work highlighted what is actually going on in the physics classrooms of India vis-à-vis physics classrooms in other countries. It was observed that there exists a difference in the attitudes and expectations of class12, undergraduate (UG) and post graduate (PG) levels students.
- As compared to class 12 and UG students, PG students were showing a slight favorable increase in their attitudes and beliefs. Deterioration was observed in the attitude, beliefs and expectation of class12 and UG students. As after the instructions given to them the unfavorable responses of these students increased and favorable responses decreased. This further indicates that instructions given were not improving students' expectation about physics and students expectations changed to be more novices like after a physics course.
- Statistically also it was found that in the clusters defined earlier there was a significant difference existing in the expectations between all the four categories (Teachers, PG, UG and XII students) with $p<0.05$. Male/female groups did not show any significant difference in their expectations in all the clusters except for concept cluster ($p=.006$), which indicates that female students were giving more stress in understanding of concepts than their male counterparts.
- There was a significant difference observed in the expectations of US students and Indian students. But the difference in the expectations between students of other countries and India was not found to be significant.

To the best of our knowledge, this study is first of its kind, not only in the state of Himachal Pradesh but, also in India and helped us to conclude that overall most of our students are still having novice like expectations, even after the completion of a full physics course. They possibly did not develop an actual understanding of physics concepts as a result of traditionally taught physics courses. This could affect their motivation and success in the course as well as career choices [70]. Therefore, there is a strong need to pay attention to

learners' beliefs and expectations when they come to classroom and efforts should be made to transfer their novice like views to expert like views by employing certain PER based strategies: Concept tests/ Peer Instruction, Just in Time Teaching (JITT), Interactive Lecture Demonstrations (ILD's) etc. The use of theses strategies will be made in future and the difference in the attitudes of learners will be observed.

5.5 Development and implementation of concept inventories

To compare the old traditional methods with new innovative techniques and to evaluate conceptual knowledge of learners, assessment/diagnostic tools such as concept inventories/surveys are designed. These inventories/surveys help to identify the concepts students don't understand and type of misconceptions prevalent in their minds. They offer a great opportunity to know the learning gaps and chalking out the researched strategies to enhance and measure learning. There are a few concept inventories/surveys developed on some selective fields of study at introductory physics level, but there is a paucity of such assessment/diagnostic tools in different areas concentrating on undergraduate physics courses of study, barring a few on the thermodynamics or material science.

For an in depth appreciation of physical behavior of a large collection of particles, statistical physics provides scaffolding as well as a foundation. Since one can say that the conceptual understanding of Statistical Physics acts as a *lingu franca* of Solid State Physics and therefore, for a working knowledge of Solid State Physics learners must have a good grasp of these concepts as they embark upon this course.

- In the process of development of a concept survey related to the basic concepts of Statistical Physics needed in Solid State Physics course for undergraduate Bachelor of Science (B.Sc, three years degree course) students, the content part of the solid state physics course being taught at undergraduate level in a typical Indian university and also in international scenario was carefully surveyed and the fundamental concepts of statistical physics were identified, without which appreciation and mastery of the solid state physics course is on a shaky foundation.
- The designed and developed Statistical Physics Concept Survey (SPCS Version 1.0) was administered.

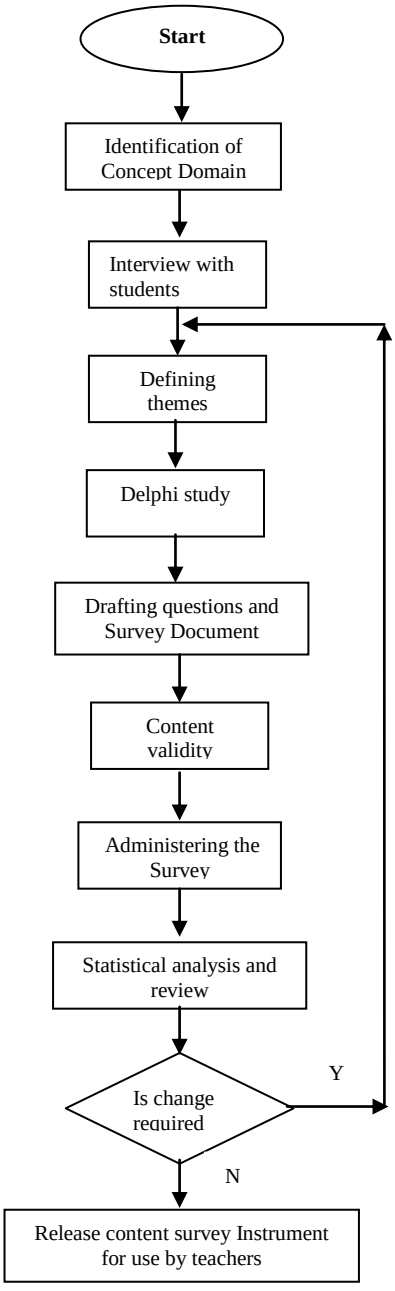

FIG.1. Algorithm used for the development of Statistical Physics Concept Survey

The steps used are shown in Figure1. SPCS consisted of 46 question items pertaining to eight themes of statistical mechanics, to assess the learner's conceptual preparation to undertake study of solid state physics at undergraduate level.

- The results of the reliability and validity of the survey after administering it to three groups respectively of, undergraduate students (the target group), postgraduate students and physics teachers (participating in a refresher course in physics at all India level) were also studied.
- The statistical indicators analyzed were pre-post item analysis and test analysis. From which it can be concluded that all the questions can differentiate students' ability quite well, the calculated value of the coefficient Cronbach's alpha was above 0.8, which was a good reliability index and the instrument was found to be reliable and suitable to be used.
- Looking at the responses given a number of epistemological beliefs and misconceptions prevailing in students' mind [71] were identified. These identified misconceptions can be used to design improved statistical physics curriculum, that takes care of these misconceptions and change them.

Thus we can conclude that the developed concept inventory can indeed help to see the student's performance vis-à-vis their understanding of basic concepts and removal of alternative conceptions/ misconceptions in a particular theme. It can also give insights into desirable changes in teaching and remedial measures which need to be taken to set the learning in the right direction.

Publications

1. Sharma, S., Ahluwalia, P.K., *"Diagnosing alternative conceptions of Fermi energy among undergraduate students"* Eur. J. Phys, **33**, pp 883-895 (2012)
2. Ahluwalia, P.K., Sharma, S., *"Epistemological beliefs, expectations and physics learning"*, Physics News: Bulletin of Indian Physics Association: Special issue on Physics Education Research, **41,** 58 (2011)
3. Sharma, S., Ahluwalia, P.K., *"Towards Cognitive Coherence in Physics Learning: Image ability of Undergraduate Solid State Physics Course"* AIP conference proceedings in international conference of physics education (ICPE) 2009, published by American Institute of Physics July 28,2010, **1263**, pp 94-97. ISBN: 9780735408166
4. Sharma, S., Sastri, OSKS., Ahluwalia, P.K., *"Design of Instructional Objectives of Undergraduate Solid State Physics Course: A First Step To Physics Education Research"* AIP conference proceedings in international conference of physics education (ICPE) 2009, published by American Institute of Physics July 28,2010, **1263**,pp171-174. ISBN: 9780735408166
5. Sharma, S., Ahluwalia, P.K., "*Development of Concept Survey Instrument for Statistical Physics Concepts in the Backdrop of Solid State Physics Course"*, Bulletin of Indian Association of Physics *Teachers,* 2010.
6. Sharma, S., Sastri, OSKS., Ahluwalia, P.K., "*Video Motion Based Analysis Using Web cam and Tracker Software to Study Flywheel Experiment"*, Bulletin of Indian Association of Physics *Teachers*, **1**, 2009.
7. Presented a paper titled "Students' *Expectations on Learning Physics: An Empirical Study*" in UGC National Workshop cum Seminar on Physics Education Research (PER): Research Based Reforms in Physics Instruction at St. Bede's College Shimla in May 2011,to be published in Multidisciplinary International ***Journal of Research: The Bede Athenaeum (ISSN 0976-0598 Print, ISSN 0976-1748 online)***
8. Presented a paper titled "*A Mismatch between Learning Styles and Teaching Styles its Influence: An Empirical Study"* in UGC National Workshop cum Seminar on Physics Education Research (PER): Research Based Reforms in Physics Instruction at St. Bede's College Shimla in May 2011, to be published in Multidisciplinary International ***Journal of Research: The Bede Atheneum (ISSN 0976-0598 Print, ISSN 0976-1748 online)***

Papers under preparation

1. Students Understanding of Statistical Mechanics at the Beginning of Solid State Physics Instructions: Development of Concept Inventory.
2. Students Understanding of Quantum Mechanics at the Beginning of Solid State Physics Instructions: Development of Concept Inventory.

Papers accepted in international conference

1. Sharma, S., Ahluwalia, P.K., "*Development and Administration of Concept Survey on Wave Particle Duality and Uncertainty Principle for Undergraduate Students: A Pilot Study*" accepted for oral presentation in The World Conference on Physics Education (WCPE) 2012 at Istanbul, Turkey.
2. Sharma, S., Ahluwalia, P.K., *"Diagnosing Alternative Conception of Fermi Energy among Undergraduate Students"* accepted for oral presentation in International conference on Physics Education ICPE 2011 at Mexico.
3. Sharma, S., Ahluwalia, P.K., *"Alternative Conceptions in Understanding the Classical and Quantum Statistical Distribution in Undergraduate Statistical Physics Course"* accepted for oral presentation in International conference on Physics Education ICPE 2011 at Mexico.
4. Sharma, S., Ahluwalia, P.K., *"Students Understanding of Statistical Mechanics at the Beginning of Solid State Physics Instructions: development of Concept Inventory"* accepted for oral presentation in GIREP-ICPE-MPTL Reims 2010 International conference.

Workshops/ seminars organized

Received UGC assistance to conduct a UGC National Workshop cum Seminar titled "*Physics Education Research (PER): Research Based Reforms in Physics Instructions*" in St. Bede's College Shimla from 21-29 May 2011.

Research Project

UGC Minor research project awarded (March 2010-August2011) titled – "*Effectiveness of research based instructional strategies in teaching solid state physics course at Undergraduate level: An Empirical Study".*N0.F.8-1(330) 2010 (MRP/NRCB).

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